SURVIVING MARS: IN-SITU PRODUCTION OF OXYGEN AND WATER

Abstract

For decades, Mars has been a target for manned space exploration. However, surviving on Mars takes oxygen, water, and food. Transportation of oxygen from Earth would be a detriment to the mission at $440,000/kg, so performing **in-situ resource utilization** on Mars would cut the cost greatly. Because evidence of water has been discovered at the surface of Mars, it is possible to use water extraction techniques and electrolysis to produce oxygen.

A mission overview has been analyzed to determine appropriate processes and rates for producing enough oxygen for a 1.5-year mission, including the use of the Sabatier methanation reaction and the reverse water gas shift (RWGS), by using experimental data of these two processes. By sending a microwave rover that extracts water, connected to a machine running these processes one synodic period in advance, the most cost-efficient method--which frees up space for return fuel -is achieved.

Motivation

Rovers already do plenty of work on Mars, so some may consider sending a manned mission a waste of funding, but a manned mission provides many advantages over a rover:

- Increased range of motion and travel
- Quick and autonomous decision-making skills
- Higher carrying capacity

By providing a system to create oxygen and water:

- Mission costs are **reduced by over $3 billion**
- Sending a system early reduces size and power
- Lowers chances of catastrophic failure

Mission Profile

Missions will occur in subsequent launch windows, which occur every 780 Earth days, or 759 Martian sol. A **sol** is a day on Mars, lasting 1.0275 Earth days, or 24 hours 39 minutes.

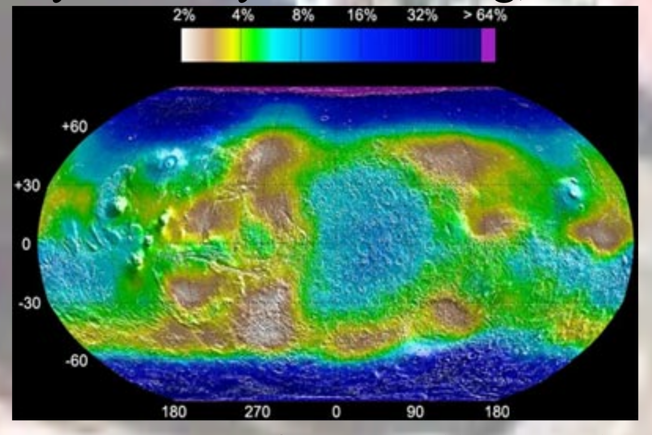
- Launches occur using Hohmann transfer orbits, a heliocentric elliptical orbit meant to save fuel.
- Travel time is **six** months

Four astronauts will travel to Mars for a **540-day** (525-sol) mission. They will in total need:

- **1815 kg** of oxygen (3.45 kg per sol)
- **5184 kg** of water (4.16 kg per sol)

The process will run for 720 sols before astronaut arrival and for the 525 sols after, bringing total runtime to **1245 sols**.

- Landing in Chryse Valles at 15° N
- System stays in covering, microwave rover deploys and rolls out



Season in Northern Hemisphere	Number of Sols (days)
Spring	194 (199.3)
Summer	178 (182.9)
Autumn	142 (145.9)
Winter	154 (158.2)
Total	668 (686.3)

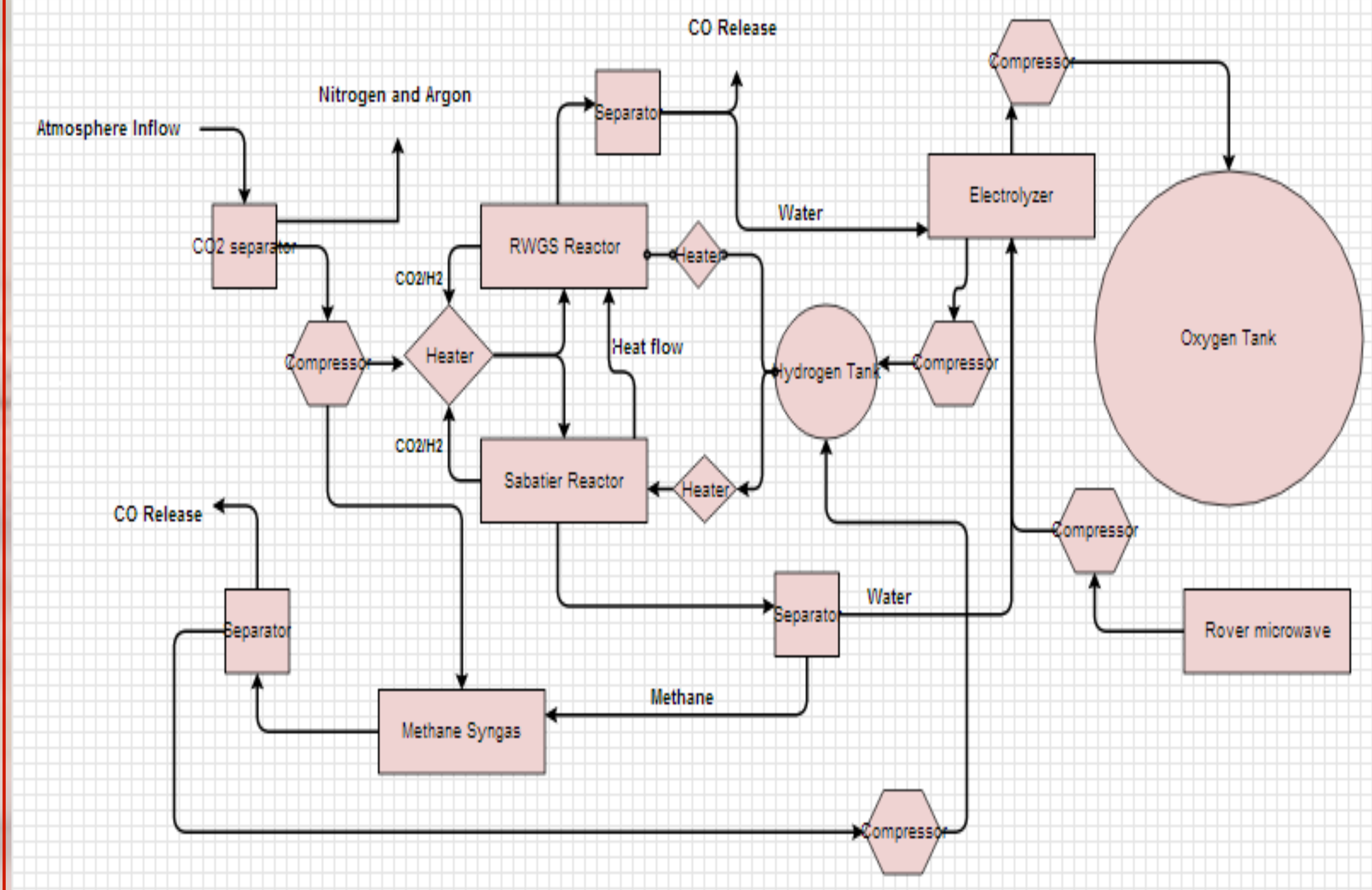
Figure: Percentage of water in soil by mass, where at 15 N there are regions of 5% water by mass
Table: Seasons of Mars: A 2028 launch would land in late summer

Decision Matrix

		Solid Oxide		Sabatier		Sab./RWGS/Syn.		RWGS	
Criteria	Weight	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
Efficiency	35	9	315	8	280	9	315	5	175
Cost	25	5	125	7	175	6	150	4	100
Power	20	3	60	7	140	7	140	4	80
Supplies	10	9	90	4	40	6	60	9	90
Practicality	10	2	20	8	80	9	90	5	50
Total	100	27	610	34	715	37	755	27	495

Table: The Sabatier-RWGS-Syngas combination will be used to produce oxygen and water most efficiently

Process Flow



Water Electrolysis: $\mathbf{H_2O \rightarrow H_2 + \frac{1}{2} O_2}$, uses 1.23 V power, 100% efficient
Sabatier Process: $\mathbf{CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O}$, $\Delta H = -165$ kJ/mol, 95% efficient
Reverse Water Gas Shift (RWGS): $\mathbf{CO_2 + H_2 \rightarrow CO + H_2O}$, $\Delta H = 41$ kJ/mol, 80% efficient
Methane Syngas: $\mathbf{CO_2 + CH_4 \rightarrow 2CO + 2H_2}$, 75% efficient

Process Reaction: $2.95\ CO_2 + 0.3\ H_2O + 0.175\ H_2 \rightarrow 2.225\ CO + 1.5\ O_2$
Microwave Rover Extraction: Average water extraction 4.16 kg/sol (95.6 g for H_2)

Closed System Flow Rates (Average oxygen production 1.46 kg/sol):
Before astronauts arrive (720 sols or 7984 hours)

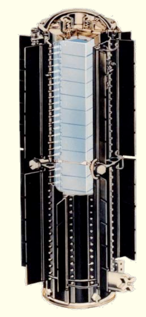
Sabatier (g/h)			RWGS (g/h)			Syngas (g/h)		
H_2	CH_4	H_2O	H_2	CO	H_2O	CH_4	CO	H_2
21.90	41.62	93.64	5.476	61.33	39.43	41.62	109.25	7.936

After astronauts arrive (525.5 sols or 5765 hours)

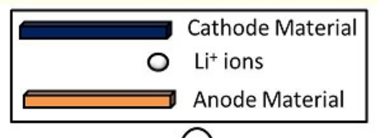
Sabatier (g/h)			RWGS (g/h)			Syngas (g/h)		
H_2	CH_4	H_2O	H_2	CO	H_2O	CH_4	CO	H_2
22.14	42.06	94.63	5.534	61.98	39.85	42.06	110.4	7.886

Power Source

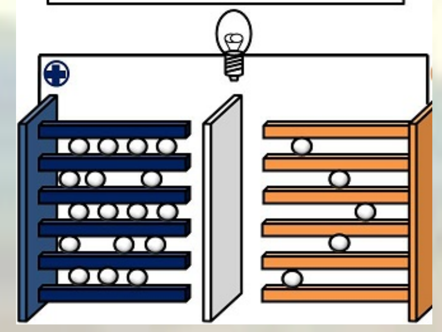
Power is a limited resource on Mars. To power the process, 1969 watts are needed, while the microwave and rover need 2700 watts. Some form of high power-density material or renewable energy must be used.



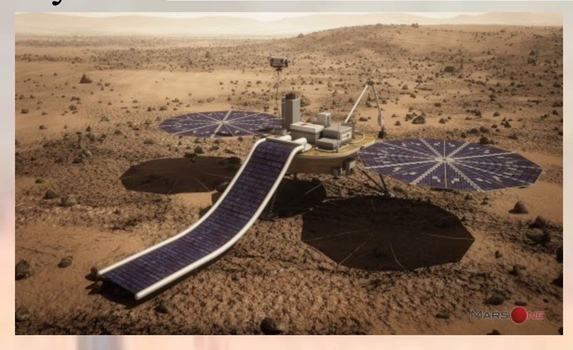
Nuclear power (500 W_{heat} and 30 $W_{electric}$ per kg)
- 5 kg plutonium produces enough heat for syngas reactor
- Keeps system heated to prevent degradation



Battery power (250 Wh/kg)
- Lithium-ion recharges at night
- Combine with nuclear heat to reduce mass needed



Solar power (average 90 W/m^2)
- 600 W/m^2 at orbit of Mars
- Dust reduces to about 300 W/m^2 at surface
- Thin-film solar cells approaching 35% efficiency
- Cleaning events allow cells to retain efficiency
- 30 m^2 roll can be used for rover



Maximum power is needed during autmn/winter, running **10.5** hours/sol, while the spring/summer has runtime of **11.5** hours per sol, giving more time to run with a lower amount of power.

Conclusion

The system will be able to deliver oxygen to a habitation module at 140 g/h. It has been shown that these flow rates are feasible, as 400 g/h of water is possible to produce. The success of a Mars mission hinges on the process system. If successful, such a system will:

- Be used on Earth, as in carbon dioxide removal
- Improve ISS environment systems
- Increase NASA budget and credibility
- Increase space exploration options
- Renew public interest

Figure: Current electrolyzer on board ISS

Space is a hostile place, but this process system will go a long way to make it safe for humanity to extend its reach to the stars.

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